ESTIMATION OF CLIMATIC PARAMETERS FROM SOLAR INDICES USING GROUND BASED DATA FROM KENYA, EAST AFRICA

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ABSTRACT
The daily meteorological data of relative humidity, maximum, minimum, and average temperatures obtained from five stations of the Kenya Meteorological Department over the period 1986 to 2005 were filtered and reduced to monthly means. Monthly data of solar indices: Sunspot number, F10.7 cm solar radio flux and Mg II core-to-wing ratio covering the same period were employed to model the meteorological variables using the linear multivariate model and applying least square fittings. Validity of the models was tested using Mean Bias Error (MBE) and Root Mean Square Error (RMSE) statistical indicators. The correlations between the observed and predicted values from the models were significant at above 95% level of confidence. The models show the effect of solar forcing on the climatic parameters at different locations in Kenya. Solar forcing of climate is evident in Kenya.

Keywords: modeling, climatic parameters, solar indices, statistical indicators.

INTRODUCTION
Climate change has for long remained an object of keen intensive research. The climate of our own Earth is rooted in the troposphere, a region in the altitude range 0 – 17 km. Attempts have been made to establish a coupling effect among the various layers of the Earth’s atmosphere. Such attempts include: Labitzke and Van Loon (1988); Rabiu et al. (2005). Impact of solar activity in Earth’s terrestrial environment is propagated from the heliosphere via the interplanetary medium to the lower atmosphere which has troposphere at its lower end. Solar activity affects the dynamics of the troposphere and influence the weather of the Earth. Rabiu and Omotosho (2003) reported negative relationship between the total column tropospheric ozone concentration in tropical Nigeria and solar activity. Rabiu et al., (2005) also established the linear dependence of surface air temperature on solar activity after obtaining negative correlation coefficients between the annual means of surface air temperature and sunspot number both at two stations. The negative correlation was explicable in terms of tropospheric heating mechanisms in response to solar activity. They asserted that the negative correlation observed at all time scales is quite in agreement with the results of Labitzke (1987), Labitzke and Van Loon (1988), Labitzke...
and Chanin (1988), Chanin (1988), and Niko-
lashkin et al. (2001) who have shown that a
negative correlation exists between solar activ-
ity and atmospheric temperature up to 50 km.
Rabiu et al. (2005) used polynomial relation-
ship to model the surface temperatures from
sunspot numbers. Ndeda et al. (2009) estab-
lished similarities in periods of Meteorological
variables over Kenya and Solar Activity peri-
ods. Scafetta and West (2008) linked the
changes in the Earth’s average surface tempera-
ture directly to two distinctly different aspects
of the Sun’s dynamics: the short-term statistical
fluctuations in the Sun’s irradiance and the
longer-term solar cycles. They had earlier
(Scafetta and West, 2003) showed that the stoch-
astic properties of the average global tempera-
ture are linked to the statistics of Total So-
lar Irradiance TSA, and estimated that ‘the Sun
could account for as much as 69% of the in-
crease in Earth’s temperature, depending on the
Total Solar Irradiance TSI reconstruction
used’ (Scafetta and West, 2007).

In this study, the climatic parameters: Relative
Humidity and Temperature, from the Kenya
Meteorological Department (KMD) for five
observatories in different climatic zones were
modeled with the solar irradiance using the
solar parameters: Sunspot Numbers (Rₚ), the
F10.7 cm solar radio flux (F10.7) and Mg II
core-to-wing ratio (Mg II) to determine the
solar forcing of the Kenyan climate. The solar
indices used in this study are the Sunspot Num-
bers (Rₚ), the F10.7 cm solar radio flux (F10.7)
and Mg II core-to-wing ratio (Mg II) which
measure the activities of the sun in the photo-
sphere, the corona and the chromospheres, re-
spectively. Sunspots are the most easily ob-
served features of the solar photosphere, while
at the same time they are important manifesta-
tions of solar activity (Győri et al., 2004). Start-
ing in 1996, space observations by the Michel-
son Doppler Imager (MDI) on Solar Helio-
physical Observatory (SOHO) have also be-
come available; (Győri et al., 2004). Sunspots
are seen as the centers of activity on the solar

The solar 10.7 cm flux is the solar flux density
measured at a wavelength of 10.7 cm in the UV
region of the spectrum. The radio emission
from the sun at a wavelength of 10.7 centime-
ters (the 10 cm flux) correlates well with the
sunspot number (Rₚ). NOAA Mg II Core-to-
wing ratio is derived from the ratio of the h to k
lines of the solar Mg II feature at 280 nm to the
background or wings at approximately 278 nm
and 282 nm. The h and k lines are variable
chromospheric emissions while the background
emissions are more stable. The Mg II Core-to-
wing ratio is a robust measure of solar chro-
mospheric activity.

RESEARCH METHODOLOGY
Modeling the Meteorological and Solar Var-
iables
Monthly data records of relative humidity
(RH), maximum temperature (MAT) and mini-
imum temperature (MIT) for the years 1986 –
2005 were obtained at five terrestrial stations
representing the regional climatic zones under
the management of the Kenya Meteorological
Department (KMD). The experimental sites
represent the different climatic variations of the
country. Monthly average temperature (AVT)
values for the same period were calculated
from MIT and MAT values. Table 1 presents
the geographical coordinates of the stations
whose data were used in this study.

Table 1: Geographical coordinates of the meteorologival stations

<table>
<thead>
<tr>
<th>Stations (Site)</th>
<th>Code</th>
<th>Latitude (°)</th>
<th>Longitude (°E)</th>
<th>Altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kericho</td>
<td>KER</td>
<td>0.4 (°S)</td>
<td>35.3</td>
<td>1946.85</td>
</tr>
<tr>
<td>Dagoretti (Nairobi)</td>
<td>NBI</td>
<td>1.3 (°S)</td>
<td>36.8</td>
<td>1771.77</td>
</tr>
<tr>
<td>Kisumu</td>
<td>KSM</td>
<td>0.1 (°S)</td>
<td>34.8</td>
<td>131.83</td>
</tr>
<tr>
<td>Mombasa</td>
<td>MSA</td>
<td>4.0 (°S)</td>
<td>39.6</td>
<td>5.41</td>
</tr>
<tr>
<td>Garissa</td>
<td>GRS</td>
<td>0.5 (°N)</td>
<td>39.6</td>
<td>120.13</td>
</tr>
</tbody>
</table>
Fig.1. Map of Kenya showing locations of the stations (Courtesy Regional Centre for Mapping of Resources for Development: RCMRD, Nairobi)
The Kericho site represents the western highlands of the rift valley province. It is located near Kericho town, in the western highlands of the rift valley, about 87 km from Lake Victoria. These features give it a fairly cold weather and persistent rains throughout the year. It is a tea zone area. Access is by road.

The Nairobi site represents the central highland region that spans the central, Nairobi and parts of Eastern provinces. The site is located within the premises of the KMD headquarters, four kilometers from the Nairobi city centre. It is in the central highlands of Kenya that influences the weather patterns here. It is accessible by road network throughout the year. Being within the city of Nairobi, the area is not forested. But it is within the neighborhoods of the forested Karen and Ngong’ estates. The soil type is loamy, and can support coffee and other seasonal food crops like maize and beans.

Kisumu site represents the influence of the smaller water body proximity of Lake Victoria, which is largely in Nyanza and parts of the Western provinces. The site is located within the shores of Lake Victoria, within the Kisumu city airport. It is a fairly hot region with a long rainy season from March to May, and short rainy season in September/October to December every year. It is accessible throughout the year by road network and by air. It is within the precinct of the Equator. The soil type is firm and rocky, and supports food crops such as sorghum, maize, beans and yams. Sugar-cane and Cotton are also grown in the neighborhood of the station.

Mombasa site represents proximity of the large Ocean environment that covers the whole of the coast province bordering the Indian Ocean. The site is located within the coastal city of Mombasa. This is the city bordering the Indian Ocean which gives it a unique humidity. The area is known for cashew nuts, cassava, palm trees and sisal.

The Garissa site represents the arid and semi-arid features that span the whole of North Eastern province of the country. The semi-arid features make the place have characteristic long periods of no rain. Sporadic rains are, however, experienced in this region. The region is also famous for raising livestock such as camels, goats and indigenous cattle.

Assuming the meteorological variable \( y \) is expressible in terms of the solar indices \( R_s, F_{10.7} \) and Mg II such that:

\[
y = y(R_s, F_{10.7}, MgII)
\]

an empirical linear multivariate model of the form below is proposed:

\[
y = A + BR_s + CF_{10.7} + DMgII
\]

Where ‘\( y \)’ is any of the meteorological variables; \( R_s \) is the sunspot number; \( F_{10.7} \) is the \( F10.7 \) cm solar radio flux index and Mg II is the Mg II core-to-wing ratio index respective values. A, B, C and D are empirical coefficients that are determined by least square fittings. The values of these coefficients are presented in the multivariate models 4 to 23.

Performance of Models

The validity of the model was tested using the statistical indicators employed by Falayi and Rabiui (2005) and El-Metwally (2005). The Mean Bias Error (MBE) and Root Mean Square Error (RMSE) were evaluated using the following equations for the meteorological variables at the five stations:

\[
MBE = \frac{\sum(y_{pred} - y_{obs})}{N}
\]

\[
RMSE = \left[ \frac{\sum(y_{pred} - y_{obs})^2}{N} \right]^{\frac{1}{2}}
\]

\( y_{pred} \) is the calculated value from the model, \( y_{obs} \) is the observed value and \( N \) is the total number of observations. The test of RMSE provides information on the short-term performance of studied model as it allows a term by term comparison of the actual deviation between the calculated value and the measured value. Iqbal (1993) and Halouani et al. (1993) have recom-
mended that a zero value of RMSE is ideal while a low MBE is desirable. The MBE and RMSE values obtained were well within the recommended values as to validate the models.

RESULTS AND DISCUSSIONS
The models represented in equations 4 to 23 show the solar forcing of RH, MAT, MIT and AVT respectively.

Relative Humidity (RH) and solar indices
KER: \( \text{RH} = -33.7938 - 0.1391 R_s + 0.0628 F_{10.7} + 382.59 \text{Mg II} \) (4)
NBI: \( \text{RH} = 18.3722 + 0.1385 R_s - 0.1714 F_{10.7} + 273.4407 \text{Mg II} \) (5)
KSM: \( \text{RH} = -50.4949 + 0.0894 R_s - 0.1383 F_{10.7} + 477.1217 \text{Mg II} \) (6)
MSA: \( \text{RH} = 58.5081 + 0.1140 R_s - 0.1375 F_{10.7} + 117.3244 \text{Mg II} \) (7)
GRS: \( \text{RH} = 167.7331 - 0.0454 R_s + 0.0888 F_{10.7} - 388.261 \text{Mg II} \) (8)

The models presented in equations 4 to 8 show the solar forcing of RH at all the stations. Models 5 to 7 for NBI, KSM and MSA indicate direct forcing of sunspot numbers and inverse forcing of \( F_{10.7} \). In KER and GRS meteorological stations; equations 4 and 8 respectively, show that \( R_s \) has negative forcing of RH while \( F_{10.7} \) has positive forcing of RH. The uniqueness of KER is attributable to the orography of KER as has been stated. The lowland semi arid features of GRS favors the inverse forcing of RH observed.

Positive forcing of Mg II on RH is evident in all the stations except GRS. GRS actually shows negative forcing of sunspot number and Mg II on RH; But positive forcing of \( F_{10.7} \) on RH. This is attributable to the semi arid features characterizing that region. The high coefficients of Mg II in the models indicate that forcing due to the chromosphere and hence the solar ultraviolet radiation is more prominent on meteorological parameters in this study compared to photosphere and corona.

Maximum Temperature (MAT) and solar indices
KER: \( \text{MAT} = 88.8943 + 0.0417 R_s - 0.0061 F_{10.7} - 251.6985 \text{Mg II} \) (9)
NBI: \( \text{MAT} = 57.8234 - 0.0545 R_s + 0.0733 F_{10.7} - 144.8584 \text{Mg II} \) (10)
KSM: \( \text{MAT} = 48.5030 - 0.0112 R_s + 0.0198 F_{10.7} - 75.5191 \text{Mg II} \) (11)
MSA: \( \text{MAT} = 16.1165 - 0.0495 R_s + 0.0391 F_{10.7} + 84.6753 \text{Mg II} \) (12)
GRS: \( \text{MAT} = 47.4955 - 0.0316 R_s + 0.0447 F_{10.7} - 60.0679 \text{Mg II} \) (13)

The models presented in equations 9 to 13 show the solar forcing of MAT at all the stations. All the models here indicate reasonable positive constant. Models in equations 10 to 13 indicate negative forcing of sunspot number on maximum temperature. The model in equation 9 for KER indicates positive forcing of \( R_s \) on MAT. Uniqueness of KER is seen in this case as was observed in relative humidity.

All stations apart from KER indicate positive forcing of the coronal index \( F_{10.7} \) on maximum temperature. The uniqueness of KER in this case shows the consistency earlier observed.

The index of the chromosphere, Mg II has negative forcing on maximum temperature in all the stations except in the case of MSA as demonstrated in equations 9 to 13. The unique case of MSA is attributed to the proximity of the Indian Ocean. The solar activities in the chromosphere, through Mg II, hence solar ultraviolet radiation has positive forcing of the maximum temperatures recorded in the coastal region.
Minimum Temperature (MIT) and solar indices

**KER:** MIT = 46.5722 + 0.0118R_s - 0.0003F_{10.7} - 139.1391Mg II  
(14)

**NBI:** MIT = 11.7282 - 0.0232R_s + 0.0202F_{10.7} + 2.2811Mg II  
(15)

**KSM:** MIT = 6.9808 - 0.0100R_s + 0.0031F_{10.7} + 39.07461Mg II  
(16)

**MSA:** MIT = -53.8120 - 0.0057R_s - 0.0310F_{10.7} + 297.5030Mg II  
(17)

**GRS:** MIT = 60.9028 - 0.0942R_s + 0.0305F_{10.7} - 149.5705Mg II  
(18)

The models presented in equations 14 to 18 show the solar forcing of MIT at all the stations. The models in equations 15 to 18 indicate that the index of the photosphere, the sunspot numbers, has negative forcing of minimum temperature. In KER (equation 14) it has positive forcing. The same reason as stated for RH and MAT over KER applies here.

NBI, KSM and GRS stations indicate positive forcing of F_{10.7} on MIT, while KER and MSA show inverse forcing. The coastal climate of MSA is the possible explanation to this deviation.

A high value of positive forcing of the index of the chromospherope, Mg II is seen in equations 15 to 17 for NBI, KSM and MSA. The exact opposite is the case in KER and GRS. While the uniqueness of KER has been explained for the cases of RH and MAT, the GRS is attributable to the unique lowland semi arid climate there.

Average Temperature (AVT) and solar indices

**KER:** AVT = 67.7332 + 0.0267R_s - 0.0032F_{10.7} - 195.4188Mg II  
(19)

**NBI:** AVT = -105.7111 - 0.0942R_s + 0.0239F_{10.7} + 472.5642Mg II  
(20)

**KSM:** AVT = 27.7419 - 0.0115F_{10.7} - 18.2222Mg II  
(21)

**MSA:** AVT = -23.8478 - 0.0276R_s + 0.0040F_{10.7} + 191.0892Mg II  
(22)

**GRS:** AVT = 54.1991 - 0.0205R_s + 0.0376F_{10.7} - 104.8192Mg II  
(23)

The models presented in equations 19 to 23 show the solar forcing of AVT at all the stations. Inverse forcing of sunspot numbers on AVT is evident in all the meteorological stations except KER as seen in models of equations 20 to 23. KER shows positive forcing. The same reasons as earlier stated for other parameters can explain the unique case of KER.

Positive forcing of F_{10.7} on AVT is evident in all the meteorological stations except KER. KER shows inverse forcing. The same reasons as earlier stated for other parameters can explain the unique case of KER.

Inverse forcing of Mg II on AVT is evident in KER, KSM and GRS but positive forcing in NBI and MSA. The positive forcing in the two major cities can be explained in terms of modifications by the Urban Heat Island effect.

Correlations between the predicted and observed values of the climatic parameters

When the models were subjected to test by using the monthly solar indices data from January 2006 to October 2007 (20 months data), the correlation coefficients between the observed and predicted climatic parameters that were obtained per meteorological station are given in Table 2 (columns 2 to 6). In column 7, we have the correlations between the observed and predicted values when data from all the stations are pooled, not station wise. This is for longer data of 100 months for all the five stations, each having the 20 months of the climatic parameters data.

From Table 2 (columns 2 to 6), the positive correlations between the observed and pre-
precited RH are quite strong in KER ($r = 0.67$) and KSM ($r = 0.52$) at the 0.01 and 0.05 levels of significance respectively. MSA gives a fair correlation at $r = 0.5$. This is an indication that the RH model can best be used in the western highland rift valley of KER and close to the large water bodies in KSM and MSA.

Only the negative correlation between observed and predicted MAT in KER ($r = -0.68$) is statistically significant at the 0.05 level (2-tailed). Some substantial positive correlation between observed and predicted MAT are in NBI and MSA. This shows that the MAT model is best applied in the low temperature area of the western highlands of rift valley, and the coastal and central highland areas to a limited extent.

From Table 2 (column 7), we see that when we have long time data, the predicted values for all parameters are statistically significant at the 0.01 level (2-tailed). The model works best for temperature (MAX, MIN, and AVT) with the correlation coefficient of about 0.9. We used 95% of confidence level to validate the models; however, there are significant correlations between the solar indices and climatic variables in the stations.

**CONCLUSIONS**

All the models in equations 4 to 23 show solar indices forcing of the climatic parameters. The statistical indicators MBE and RMSE validate the models as recommended by Iqbal, (1993) and Halouani et al. (1993). The following conclusions can be drawn from the models:

1. The photosphere through its index, the sunspot number has positive forcing of Relative humidity (RH); while the corona, through its index F10.7 cm solar radio flux has negative forcing of RH in Kenya, except for KER and GRS meteorological stations where the scenario is opposite. Solar Ultraviolet (UV) radiation through the proxy Mg II core to wing ratio which is the index of the chromosphere has positive forcing of RH in Kenya. The lowland semi arid region of north Eastern Kenya influences the opposite trend of forcing. The models give predicted values that correlate well with the observed values for KER, KSM and MSA when short time data are used; but they give predicted values that correlate better with observed values when longer duration data are used.

2. The photosphere through its index, the sunspot number has negative forcing of Temperature (MAT, MIT and AVT); while the corona, through its index F10.7 has positive forcing of Temperature in Kenya, except for KER meteorological station. Solar UV radiation through the proxy Mg II, which is the index of the chromosphere, has negative forcing of MAT in Kenya, except for MSA where there is negative forcing. Mg II, however, shows general negative forcing of MIT and AVT in majority of the stations considered in this study. Positive forcing is, however, prevalent in KER and GRS for MIT; and in NBI and MSA for

<table>
<thead>
<tr>
<th>Rh</th>
<th>KER</th>
<th>KSM</th>
<th>MSA</th>
<th>GRS</th>
<th>Corr. Coefficient (All stations’ data used): 100 months data.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH</td>
<td>-0.15</td>
<td>0.67**</td>
<td>0.52**</td>
<td>0.52</td>
<td>0.33</td>
</tr>
<tr>
<td>MAT</td>
<td>0.52</td>
<td>-0.68**</td>
<td>0.29</td>
<td>0.58</td>
<td>-0.08</td>
</tr>
<tr>
<td>MIT</td>
<td>0.21</td>
<td>0.21</td>
<td>-0.3</td>
<td>0.14</td>
<td>0.26</td>
</tr>
<tr>
<td>AVT</td>
<td>-0.35</td>
<td>0.34</td>
<td>0.34</td>
<td>0.02</td>
<td>0.26</td>
</tr>
</tbody>
</table>

**Correlation significant at the 0.01 level (2-tailed). *Correlation Significant at the 0.05 level (2-tailed)**

**Table 2. Correlations between the model predicted and observed values of climatic parameters per station**

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Scafetta N., and West, B. J. (2007) Phenomenological reconstructions of the solar sig-